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(54) **FLIGHT CONTROL SURFACE SEAL**

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(51) **Int. Cl.**

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B64C 3/50	(2006.01)
B64C 7/00	(2006.01)
B64C 9/02	(2006.01)
F16J 15/02	(2006.01)

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(58) **Field of Classification Search**

USPC 244/130, 131; 277/644

See application file for complete search history.

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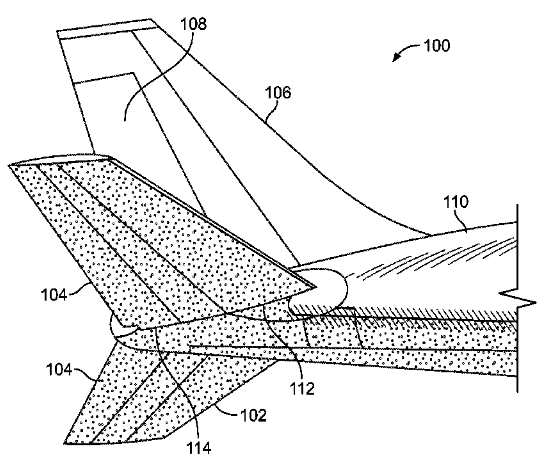
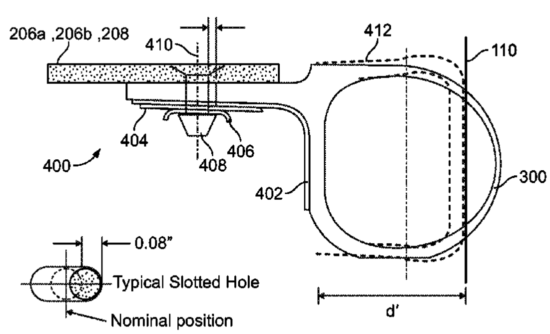
(57) **ABSTRACT**

A system and method for reducing aerodynamic drag is disclosed. A compression seal is attached to the inboard edges of the stabilizer and elevators of an airplane. The seal blocks airflow in a gap located between these inboard edges and a fuselage. The shape of the compression seal changes as the shape of the gap changes due to movement of the stabilizer and elevators during flight to effectively block airflow through the gap during flight. By blocking the airflow, the seal reduces the aerodynamic drag of the airplane.

18 Claims, 4 Drawing Sheets





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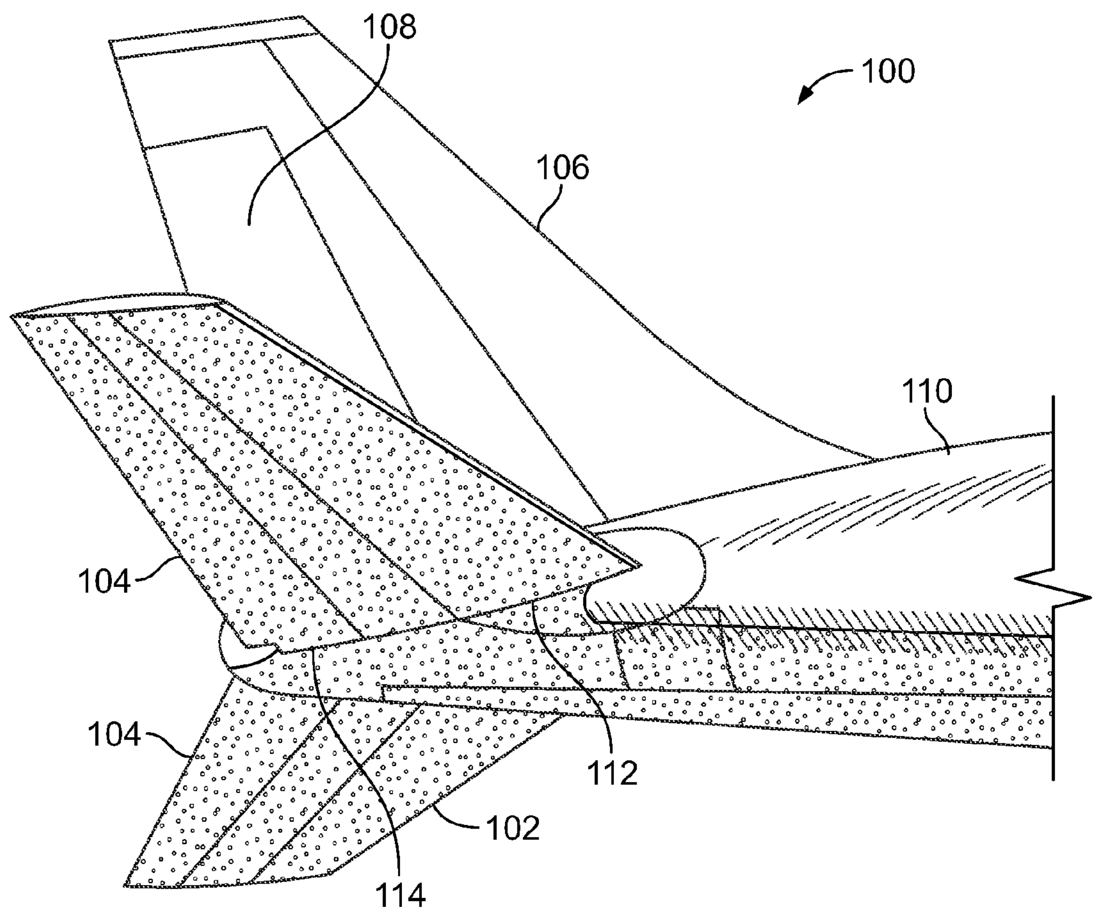

FIG. 1

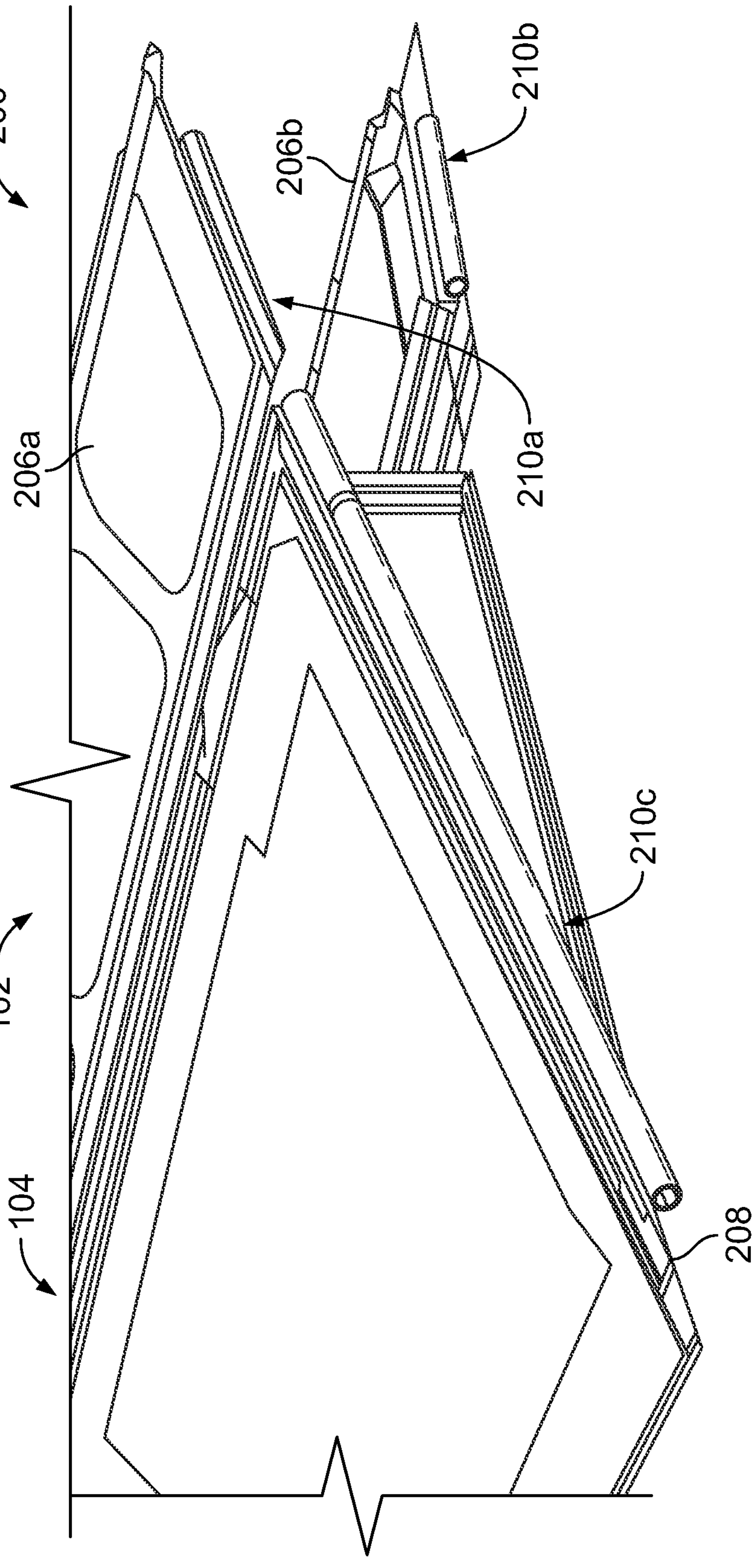

FIG. 2

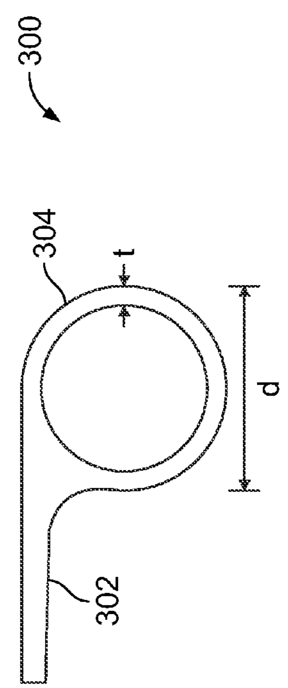
300
304
t
d
302

FIG. 3

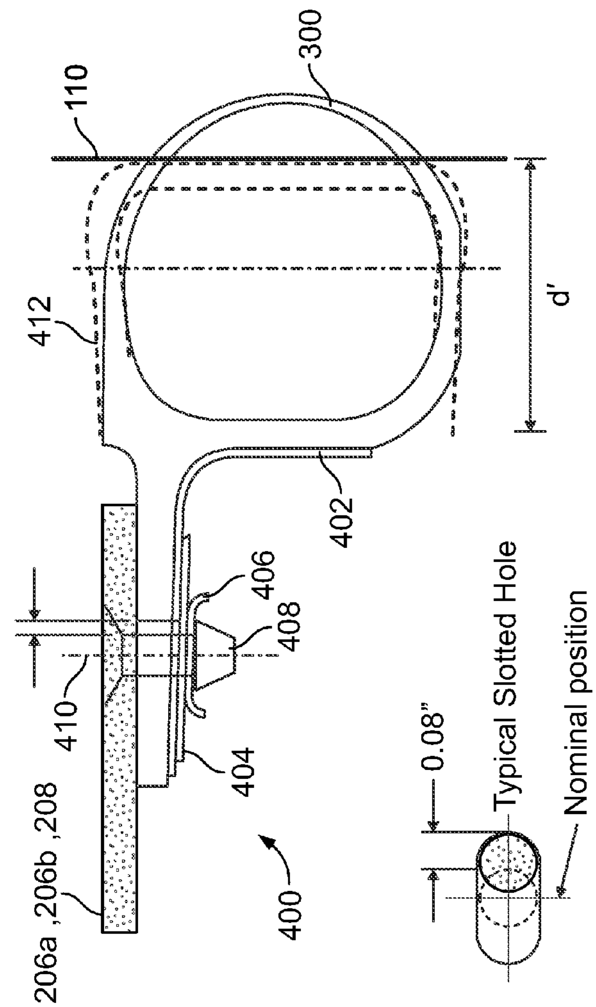
110
300
412
d'
402
406
408
410
404
206a ,206b ,208
400
0.08"
Typical Slotted Hole
Nominal position

FIG. 4

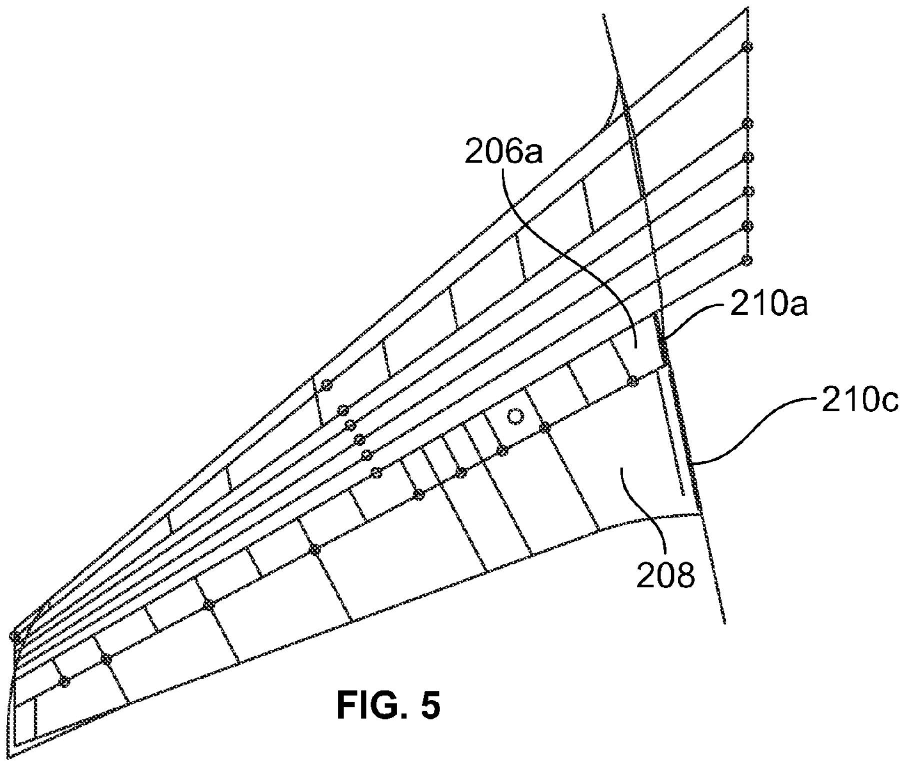

FIG. 5

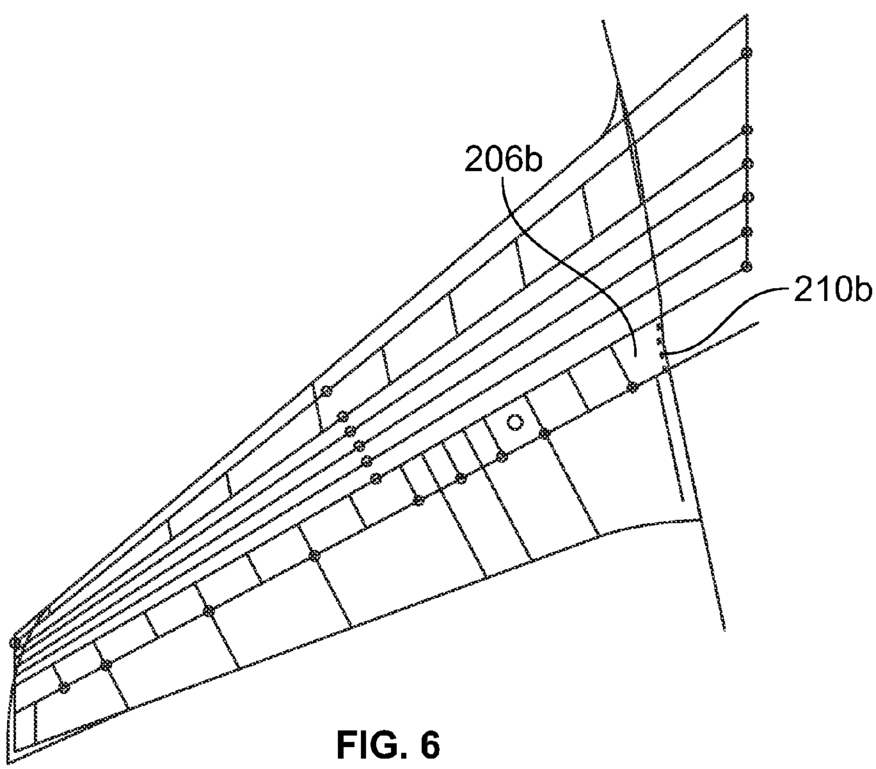

FIG. 6

FLIGHT CONTROL SURFACE SEAL

FIELD

The disclosure is related to reducing aerodynamic drag of an airplane and, more particularly, to flight control surface seals that reduce aerodynamic drag.

BACKGROUND

An airplane includes flight control surfaces that a pilot can adjust to control the aircraft's flight attitude. Airplane design determines what flight control surfaces are available on a particular airplane. Typical flight control surfaces include the wing's slats, flaps, spoilers, and ailerons; vertical and horizontal stabilizers; rudders, and elevators.

A horizontal stabilizer is a horizontal wing attached to the aft end of the fuselage of an airplane to trim the airplane about the longitudinal axis by providing a stabilizing force to the aft end of the airplane. While some horizontal stabilizers are fixed, others can be moved during flight. These movable horizontal stabilizers, which may be referred to as variable incidence horizontal stabilizers, allow the pilot to adjust the angle of the horizontal stabilizer based on the aircraft's longitudinal stability parameters, such as center of gravity location.

Elevators are flight control surfaces that control the aircraft's longitudinal attitude by changing the vertical loads on the aft end of the fuselage. Elevators are usually hinged to the aft end of the horizontal stabilizer.

Since these movable horizontal stabilizers and elevators move relative to the fuselage, a gap exists between these flight control surfaces and the fuselage except at the point where the surface is attached to the fuselage (i.e., the pivot point of the surface). Since most aft fuselages are convex curved about the longitudinal axis of the airplane, the gap between the movable horizontal stabilizer inboard edge and the fuselage is not constant. This gap normally increases as the stabilizer is moved more from its neutral position. This is also true of the elevator. As the size of the gap increases, so too does the aerodynamic drag of the airplane, which impacts the performance of the airplane.

SUMMARY

A system and method for reducing aerodynamic drag of an airplane is disclosed. The system includes a flight control surface of an airplane and a seal connected to the flight control surface. The seal blocks airflow through a gap located between the flight control surface and a fixed structure of the airplane. In a preferred embodiment, the flight control surface is a horizontal stabilizer or an elevator, the fixed structure is a fuselage, and the seal is a bulb seal.

The method includes placing an exterior surface of a seal adjacent to an inboard edge of a flight control surface of an airplane, positioning a fastener adjacent to an opposite exterior surface of the seal, and attaching the seal to the flight control surface with the fastener. The seal fills a gap located between the flight control surface and a fixed structure of the airplane. The method further includes applying a low friction coating, such as Teflon® paint, on the fixed structure.

The features, functions, and advantages that have been discussed can be achieved independently in various embodiments or may be combined in yet other embodiments further details of which can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Presently preferred embodiments are described below in conjunction with the appended drawing figures, wherein like reference numerals refer to like elements in the various figures, and wherein:

FIG. **1** is an illustration of an empennage of an airplane, according to an example;

FIG. **2** is an illustration of an isometric view of a horizontal stabilizer and an elevator, according to an example;

FIG. **3** is an illustration of a cross-sectional view of a seal, according to an example;

FIG. **4** is an illustration of a cross-sectional view of a fastener for attaching the seal to the horizontal stabilizer and the elevator, according to an example;

FIG. **5** is an illustration of a view looking down on the stabilizer and elevator identifying a location for attaching the seal, according to an example; and

FIG. **6** is an illustration of a view looking up on the stabilizer and elevator identifying a location for attaching the seal, according to an example.

The drawings are for the purpose of illustrating example embodiments, but it is understood that the inventions are not limited to the arrangements and instrumentality shown in the drawings.

DETAILED DESCRIPTION

FIG. **1** is an illustration of an empennage **100** of an airplane. The empennage **100**, also known as the tail or tail assembly, contributes to the stability and the control of the airplane. The empennage **100** includes a horizontal stabilizer **102** with elevators **104**. The empennage **100** also includes a vertical stabilizer **106** with a rudder **108**. The horizontal stabilizer **102** and vertical stabilizer **104** are connected to a fuselage **110** of the airplane.

As the horizontal stabilizer **102** and the elevators **104** move relative to the fuselage **110**, a gap between the fuselage **110** and either the horizontal stabilizer **102** or elevators **104** changes size. To reduce aerodynamic drag, a seal is attached to inboard edges **112** of the horizontal stabilizer **102** and inboard edges **114** of the elevators **104**. The seal expands and compresses as the gap changes size to block airflow between these flight control surfaces **102**, **104** and the fuselage **110**.

FIG. **2** is an isometric view **200** of the horizontal stabilizer **102** and the elevator **104**. The view **200** depicts trailing edge panels **206***a* and **206***b* of the horizontal stabilizer **102** and an elevator panel **208** of the elevator **104**. Seals **210***a* and **210***b* are attached to each of the panels **206***a* and **206***b*, respectively. A seal **210***c* is also attached to the elevator panel **208**.

FIG. **3** is a cross-sectional view of a seal **300** that may be used for the seals **210***a*, **210***b*, and **210***c*. The seal **300** is a compression seal and is depicted in FIG. **3** as a bulb seal and, in particular, a P-bulb seal. The bulb seal is flexible and changes shape as pressures are exerted on the exterior of the seal **300**. The flexible nature of the seal **300** allows it to expand and contract to fill the variability of the gap throughout the normal range of the horizontal stabilizer **102** and elevator **104**. Other flexible seal types may also be used.

The dimensions of the seal **300** depend on the design of the airplane and, more specifically, the size of the gap between the flight control surfaces **102**, **104** and the fuselage **110** as the flight control surfaces **102**, **104** move. As the elevator **104** typically has a greater range of motion than the horizontal stabilizer **102**, different seal dimensions may be used for the different panels **206***a*, **206***b*, and **208**. For example, the diameter of the bulb may be larger for the seal **210***c* attached to the elevator panel **208** than the seals **210***a* and **210***b* attached to the trailing edge panels **206***a* and **206***b*.

In one example, the diameter (d) of the bulb from the exterior edges of the bulb may be approximately 1.8" and the thickness of the bulb wall (t) may be approximately 0.08" when not subjected to external forces. In other examples, the diameter (d) may be between 1" and 3" and the bulb wall thickness (t) may be between 0.5" and 1.5". In other examples, the diameter (d) may be between 0.5" and 5" and the bulb thickness (t) may be between 0.1" and 2".

The P-bulb seal includes an attachment surface **302**, sometimes referred to as a handle or lip. The attachment surface **302** facilitates attachment of the seal **300** to the panels **206***a*, **206***b*, and **208**. While other mechanisms and surfaces may be used to attach the seal **300** to the panels **206***a*, **206***b*, and **208**, P-bulb seals are readily available and convenient to use.

The seal **300** is composed of a non-metallic material, preferably, silicone. In a preferred embodiment, the seal is composed of BMS 1-57 Type 2 silicone. Other non-metallic materials, such as rubber, may also be used.

The seal **300** may also be covered with an external covering **304**, such as a polyester fabric or other protective material. For example, the external covering **304** may include one or more layers of Mohawk D2000 Dacron® fabric or HT 2002 Nomex® fabric. Preferably, the external covering **304** has two reinforced plies of one of these two fabrics. In this example, the thickness of the external covering **304** is approximately 0.12". In other examples, the thickness of the external covering **304** may be between 0.05" and 0.25".

The bulb seal **300** is attached to the panels **206**, **208** with a row of fasteners. In one example, the fasteners are spaced 1.875" apart. In other examples, the fasteners are spaced between 1.5" and 2" apart. In other examples, the fasteners are spaced between 1" and 3" apart.

FIG. **4** is a cross-sectional view of a fastener **400**. The fastener **400** includes a seal retainer **402**, a nut plate retainer strip **404**, a nut plate **406**, and a bolt **408**. A slotted hole **410** is located in the seal **300** and the seal retainer **402**. While FIG. **4** depicts a typical slotted hole, other dimensions are suitable.

The seal retainer **402** provides support to the seal **300** as external pressures from the fuselage **110** deform the seal **300**. In one example, the seal retainer **402** is formed using one or more layers of carbon or carbon composite fabric. Preferably, the seal retainer **402** is formed from four plies of carbon composite fabric (e.g., BMS 8-256) having a thickness of approximately 0.034". In other examples, the thickness of the seal retainer **402** may be between 0.02" and 0.05" or between 0.01" and 0.1". Additionally, in other examples, the seal retainer **402** may be formed using one or more layers of fiberglass fabric, such as 4-ply 181 fiberglass fabric, or other suitable materials.

The nut plate retainer strip **404** is located between the seal retainer **402** and the nut plate **406**. A bolt **408** attaches the seal retainer **402** to the panels **206**, **208**. The size of the bolt depends on the type of nut plate **406** selected. Preferably, the bolt is a 3/16" bolt, but other bolt types may also be used. In one example, a 3/16" titanium BACB30VF bolt is used in a BACN11G nut plate. The slotted holes **410** in the seal **300** and the seal retainer **402** allow the bolt **408** to slide left and right as the bolt **408** is installed. While a slotted hole is not necessary, it is easier to install the bolt **408** with this ability to adjust the location of the bolt **408** within the slotted holes **410**.

To attach the seal **300** to the panels **206**, **208**, an installer places an exterior surface of the attachment surface **302** adjacent to the inboard edges **112**, **114** of the panels **206**, **208** such that the seal **300** extends from the panels **206**, **208** and contacts the fuselage **110**. During installation, the seal **300** is compressed against the fuselage **210**. The amount of compression is based on the range of motion of the flight control surfaces **102**, **104** and the maximum width of the gap expected.

The installer positions the fastener **400** adjacent to an opposite side of the exterior of the attachment surface **302** aligning the slotted holes **410** in the seal **300** and the seal retainer **402**. The installer then positions the nut plate strip **404** and the nut plate **406** on the seal retainer **402**. The installer then installs bolts **408** through the nut plate **406**, the nut plate strip **404**, the seal retainer **402**, and the panels **206**, **208**.

While FIG. **4** depicts a particular fastener design, it is understood that other attachment mechanisms may be used. It is also understood that the fastener **400** may be modified to include more or less components. The fastener **400** may also use different materials and dimensions than described herein.

FIG. **4** also depicts how the seal **300** changes shape based on external pressures. As the seal **300** is pressed against the side of the fuselage **110** when the panels **206**, **208** move closer to the fuselage **110**, the seal **300** deforms as shown by the dotted deformation line **412**. For example, the diameter (d') of the bulb from the exterior edges of the bulb may be reduced from 1.8" to 1.5". While this is only one example, it shows how the seal **300** is able to block the airflow between the fuselage **110** and the panels **206**, **208** as the gap size changes.

In addition to the contact pressure from the fuselage **110**, the seal **300** is also subjected to friction as it moves along the fuselage **110**. To reduce friction, a low friction coating may be applied to the fuselage **110**. For example, a polytetrafluoroethylene (PTFE) (i.e., Teflon®) coating or paint may be applied to the fuselage.

The seal **300** was flight tested on an on a Boeing 787-9 airplane. FIG. **5** depicts where the seal **210***a* was attached to the trailing edge panel **206***a* of the horizontal stabilizer **102** and the seal **210***c* was attached to the elevator panel **208** of the elevator **104**. FIG. **6** depicts where the seal **210***b* was attached to the trailing edge panel **206***b* of the horizontal stabilizer **102**. Flight test data confirms that the seal **300** reduces aerodynamic drag. Test results showed that the seal **300** improved drag by an equivalent of 600 pounds of airplane weight. This improvement results in a more fuel efficient operation of the airplane.

While the seal was tested on a Boeing 787-9 airplane, the use of the seal **300** is not limited to any particular type of airplane. For example, the seal **300** may be used on private airplanes and military airplanes, e.g., tanker aircraft, in addition to commercial airplanes. Moreover, the seal **300** can be retrofitted onto older airplanes that are currently operating without the seal **300**.

While the seal **300** was described with respect to the horizontal stabilizer **102** and the elevators **104**, the seal **300** may be useful for reducing drag between a fixed structure of the airplane (e.g., the fuselage **110**, fixed wing portions) and other control surfaces. For example, the seal **300** may be attached to flight control surfaces associated with the wing (e.g., slats, flaps, spoilers, and ailerons) or the vertical stabilizer **106** (e.g., the rudder **108**). As another example, the seal **300** may be useful for reducing drag between two control surfaces, such as between the horizontal stabilizer **102** and the elevators **104**.

By reducing aerodynamic drag through the use of the seal **300**, the airplane becomes more fuel efficient. Moreover, the fuel savings obtained from use of the seal **300** are much greater than the cost of adding the seal **300** to the airplane. As a result, the cost of operating the airplane and the impact to the environment is reduced.

It is intended that the foregoing detailed description be regarded as illustrative rather than limiting and that it is understood that the following claims including all equivalents are intended to define the scope of the invention. The claims should not be read as limited to the described order or elements unless stated to that effect. Therefore, all embodiments that come within the scope and spirit of the following claims and equivalents thereto are claimed as the invention.

We claim:

1. A system for reducing aerodynamic drag, comprising:
an adjustable flight control surface of an airplane;
a bulb seal connected to the flight control surface such that the bulb seal blocks airflow through a non-constant gap located between the flight control surface and a fuselage of the airplane; and
a fastener connecting the bulb seal to the flight control surface, the fastener including
a non-metallic seal retainer extending along an attachment surface of the bulb seal, wherein the non-metallic seal retainer is configured to provide support to the bulb seal as external pressures from the fuselage deform the bulb seal,
a nut plate retainer strip located between a nut plate and the seal retainer, and
a bolt that connects the nut plate to the flight control surface through the nut plate retainer strip, the seal retainer, and the attachment surface of the bulb seal.

2. The system of claim **1**, wherein the bulb seal is composed of a non-metallic material.

3. The system of claim **1**, wherein the bulb seal is composed of silicone.

4. The system of claim **1**, wherein the flight control surface is a horizontal stabilizer.

5. The system of claim **1**, wherein the flight control surface is an elevator.

6. The system of claim **1**, wherein the bulb seal is connected to the flight control surface with a row of fasteners through a seal retainer.

7. The system of claim **6**, wherein the retainer is composed of a carbon composite fabric.

8. The system of claim **6**, wherein the bulb seal and the seal retainer include slotted holes.

9. The system of claim **8**, wherein the row of fasteners connects the seal retainer to the flight control surface through the slotted holes of the seal retainer and the bulb seal.

10. A method of reducing aerodynamic drag, comprising:
placing an exterior surface of a handle of a P-bulb seal adjacent to an inboard edge of an adjustable flight control surface of an airplane;
positioning a fastener adjacent to an opposite exterior surface of the handle of the P-bulb seal;
locating a nut plate retainer strip between a nut plate and a non-metallic seal retainer;
utilizing a bolt to connect the nut plate to the flight control surface through the nut plate retainer strip, the seal retainer, and the handle of a P-bulb seal; and
attaching the handle of the P-bulb seal to the flight control surface with the fastener, wherein a bulb of the P-bulb seal fills a non-constant gap located between the flight control surface and a fuselage of the airplane, and
wherein the non-metallic seal retainer is configured to provide support to the P-bulb seal as external pressures from the fuselage deform the P-bulb seal.

11. The method of claim **10**, further comprising applying a low friction coating on the fuselage.

12. The method of claim **10**, wherein the flight control surface is a trailing edge panel of a horizontal stabilizer.

13. The method of claim **10**, wherein the flight control surface is an elevator panel of an elevator.

14. The method of claim **10**, wherein the bulb of the P-bulb seal changes shape as the flight control surface moves relative to the fuselage during flight.

15. A system for reducing aerodynamic drag, comprising:
a fuselage of an airplane;
an adjustable flight control surface of the airplane, wherein a non-constant gap is located between the fuselage and the flight control surface;
a seal attached to the flight control surface that contacts the fuselage as the flight control surface is adjustable during flight; and
a fastener connecting the bulb seal to the flight control surface, the fastener including
a non-metallic seal retainer extending along an attachment surface of the bulb seal, wherein the non-metallic seal retainer is configured to provide support to the bulb seal as external pressures from the fuselage deform the bulb seal,
a nut plate retainer strip located between a nut plate and the seal retainer, and
a bolt that connects the nut plate to the flight control surface through the nut plate retainer strip, the seal retainer, and the attachment surface of the bulb seal.

16. The system of claim **15**, wherein the flight control surface is a horizontal stabilizer.

17. The system of claim **15**, wherein the flight control surface is an elevator.

18. The system of claim **15**, wherein the seal is a compression seal.

* * * * *